Modelling of Laser Produced Gadolinium Plasma Source at 6.7 nm

ASML

V.Novikov[1], V.Ivanov[2], K.Koshelev[2], V.Krivtsun[2], R.Kildiyarova[2], A.Grushin[1], A.Solomyannaya[1], I.Vichev[1], V.Banine[3], D.Glushkov[3], A.Yakunin[3]

[1]Keldysh Institute of Applied Mathematics RAS, 4 Miusskaya sq., Moscow, 125047 Russia
[2]Institute of Spectroscopy RAS, 5 Fizicheskaya st., Troitsk, Moscow region , 142090 Russia
[3]ASML, Veldhoven, The Netherlands

Atomic Model

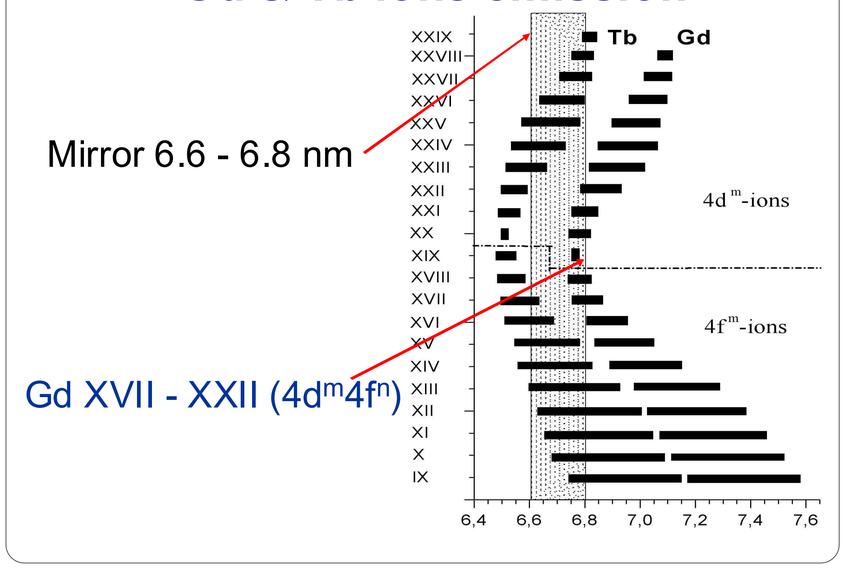
- Detailed data with experimentally verified lines positions
- Close in energy ion states are united to superstates
- Detailed transition energies between superstates are averaged inside intervals of photon energies
- The effective oscillator strengths and collisional strengths are calculated for every transition and photon energy interval
- These data are memorized for all ion superstates and for all transitions between superstates and are used when calculating the rates at given temperature, density and radiation field
- The intersection between spectral lines of different ions inside photon energy group is calculated by using effective line widths and memorized data

Optimization plan

Emissivity tables analysis
Simple model for homogeneous target
Wide range 2D calculations with the code RZLINE

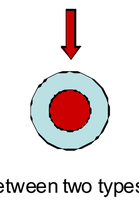
Target – plate, droplet, with admixtures, nonhomogeneous in space,etc.
Laser – CO_2, Nd 1-, 2-, 3- harmonics
Pulse – duration, focal spot, prepulse, time & space profile
Energy input – reflection, absorption

Gd & Tb ions emission



Optimal band for Gd at λ= 6.775 nm ±0.25%

RZLINE code



2D Euler RMHD

Energy fluxes to and from droplet:
absorption and reflection of laser pulse,
electron and ion thermo-conductivity,
radiative transfer in ~100 spectral groups,
evaporation and condensation of target,
ionization and recombination of plasma.

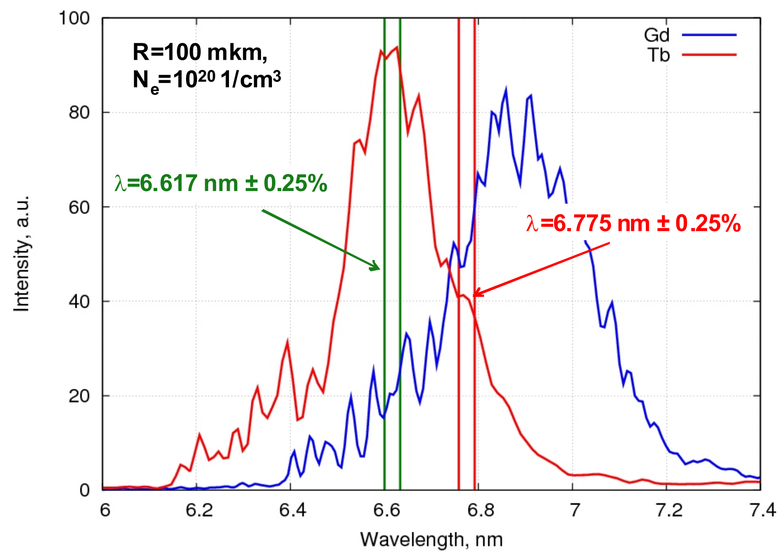
Special interpolation between two types of tables is used:
1.Transparent case table
2.Optically thick case table (nontrasparent in band)

Diffusion-like spectral radiation transport:
calculation of EUV source size,
detailed spectra,
anisotropy of EUV radiation.

Temperature	1 – 500 eV
Electron density	10^{14} – 10^{23} 1/cm^3
Photon energy range	1 – 1000 eV

Nonhomogeneous grid ~ 10^5 r,z cells
Calculation time ~ 2 hours on PC 2.1 GHz

Comparison of Gd & Tb spectra at T=140 eV



Simple estimation of conversion factor

(homogeneous droplet with radius R)

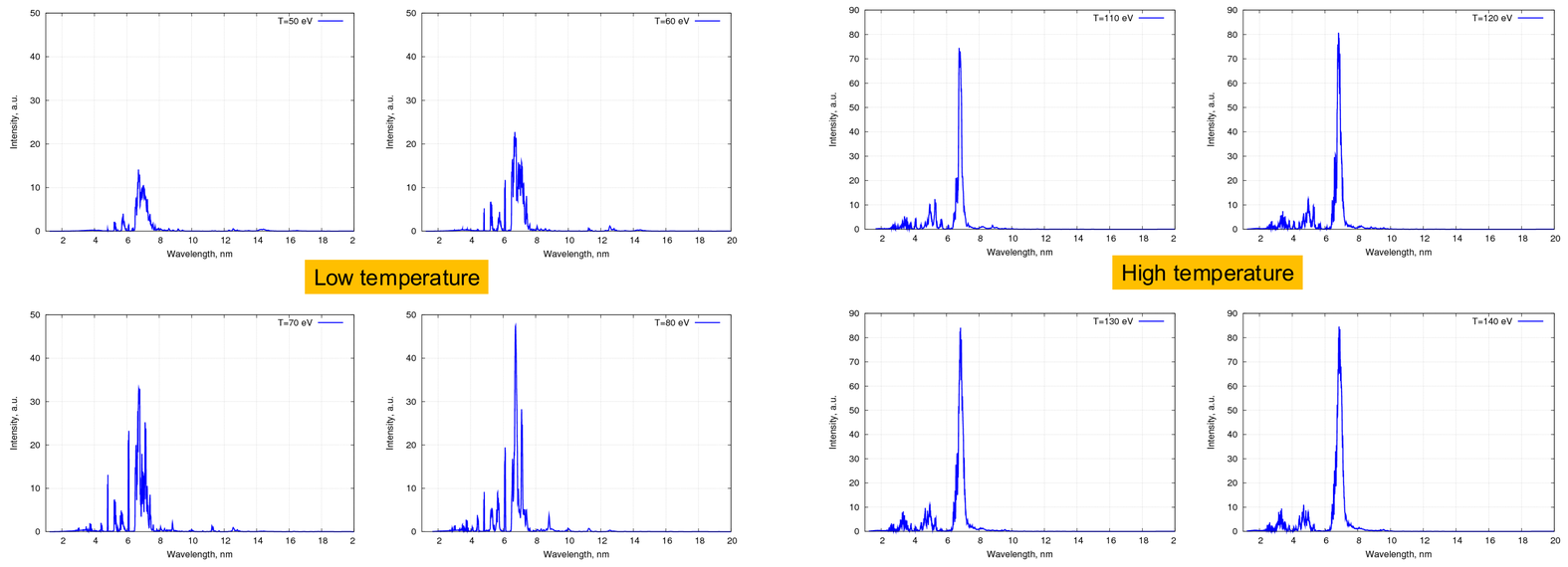
$$Cf=\frac{Q_{\text{in band}}\cdot\Delta t}{4\cdot E}$$

$$\Delta t=R/v,\quad v=\sqrt{3TZ_0/M}$$

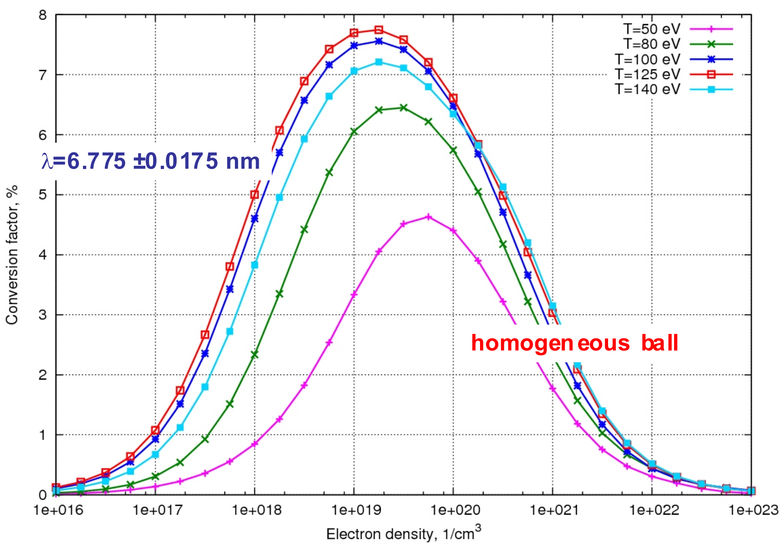
$$R\kappa=1$$

E is the internal energy of droplet
T is the temperature
Z_0 is the mean ion charge
M is the ion mass
k is the absorption coefficient in band

Calculated Gd spectra, $N_e=10^{20}$ 1/cm^3, R=100 mkm

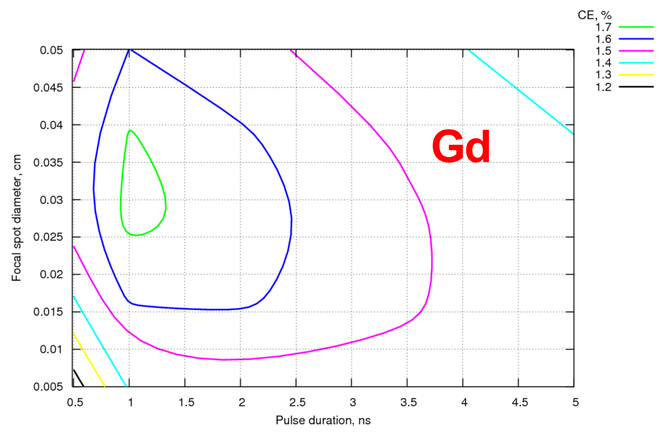


Gd conversion factor

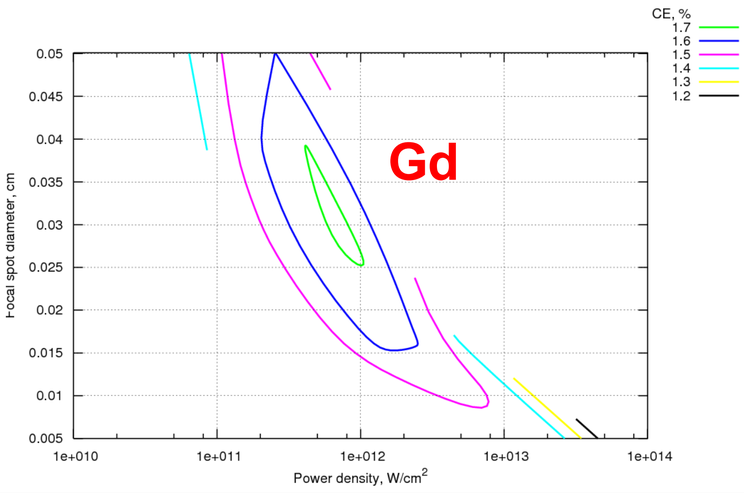


RZLINE calculation, Nd laser, E=0.5J, flat target

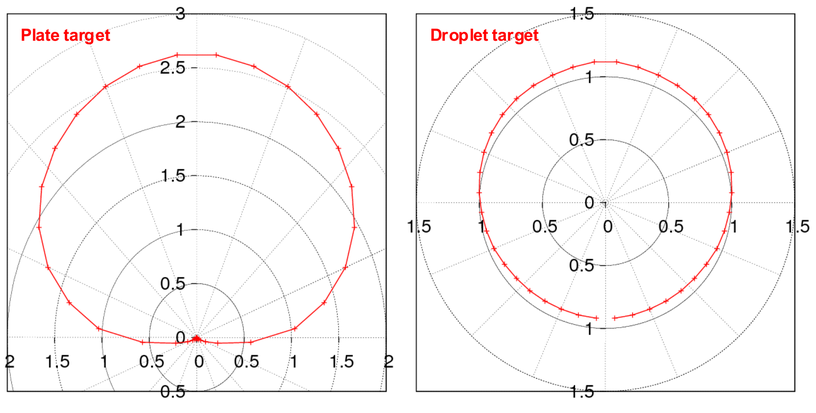
CE vs pulse duration & focal spot



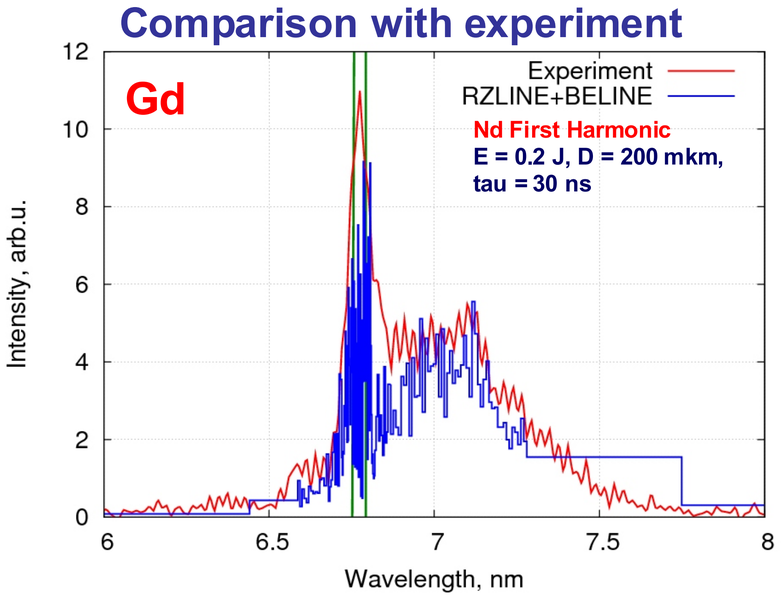
CE vs power density & focal spot



Anisotropy of BEUV radiation



Comparison with experiment



Conclusion

➢ Modelling of Gd LPP emission around 6.7 nm was performed and sensitivity of the emission efficiency and spectrum to power density is investigated

➢ Simple model:
Estimation for homogeneous Gd plasma balls shows maximum conversion efficiency about 7.5% at **λ=6.775 nm in 0.5% band**

➢ Realistic model:
Modelling by using the code RZLINE gives for solid flat Gd target CE~ 2-3 %